(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 January 2001 (11.01.2001)

PCT

(10) International Publication Number
WO 01/03257 Al

(51) International Patent Classification: HOIS 3/042

(21) International Application Number. PCT/DKOO/00356

(22) International Filing Date: 30 June 2000 (30.06.2000)

(25) Filing Language: Englisb

(26) Publication Language: Englisb

(30) Priority Data:
PA 1999 00961 2 July 1999 (02.07.1999) DK

(71) Applicant *(for all designated States except US):* ASAH MEDICO A/S [DK/DK]; Valseholmen 11-13, DK-2650 Hvidovre (DK).

(72) Inventors; and
(75) Inventors/Applicants *(Pr US only):* . BALLE-PETERSEN, Olav [DK/DK]; Langehjergvej 317, DK-3050 Humlebnk (DK). BRUUN-LARSEN, Morten [DK/DK]; Fortly 3B, DK-2610 R0dovre (DK).

(74) Agent: PLOUGMANN, VINGTOFT & PARTNERS A/S; Sankt Anne Plads 11, P.O. Box 3007, DK-1021 Copenhagen K (DK).

(81) Designated States *(national):* AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FT, Fl (utility model), GB, GD, GE, GH, GM, HE, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KR (utility model), KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, *SE,* SG, SI, SK, SK (utility model), SL,TJ, TM, TR, Tl TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional):* ARIPO patent (OH, GM, ICE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, *BE,* CH, CY, DE, DK, ES, Fl, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Publisbed:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A SOLID-STATE LASER CRYSTAL ASSEMBLY

(57) Abstract: A solid-state laser crystal assembly is provided, comprising a solid-state laser crystal for emission of a laser beam, a cooling member for dissipation of heat generated by the laser and baving a cooling surface, the solid-state laser crystal being positioned adjacent to the cooling surface, and a bolder for bolding the cooling member and the solid-state laser crystal so that tbe solid-state laser crystal is in beat dissipating contact with the cooling surface. The solid-state laser crystal is, thus, removahly positioned at the cooling surface of the cooling member and is, during operation of tbe assembly, beld in this position by the holder. The laser crystal assembly may further comprise a first transparent tbermally conductive member being positioned between the cooling surface and the solid-state laser crystal. The first transparent conductive member may for example be made of sapphire.

A SOLID-STATE LASER CRYSTAL ASSEMBLY

FIELD OF THE INVENTION

The present invention relates to a solid-state laser crystal assembly facilitating cooling of a solid-state laser crystal during emission of light.

BACKGROUND OF THE INVENTION

In US 5,553,088 a solid-state laser crystal assembly is disclosed with a solid-state disc laser that is pumped with a pumping light source. The solid-state laser crystal is positioned at a cooling surface of a cooling member for dissipation of heat generated in the solid-state laser crystal. The cooling member forms a carrier for the solid-state laser crystal. The radiated laser beam propagates approximately parallel to the temperature gradient in the laser. Due to heat dissipation into the cooling member, the assembly facilitates pumping of the laser with a high pumping power. Further, since the radiated laser beam propagates approximately parallel to the temperature gradient in the solid body, the beam is exposed to the same temperature gradient in all cross-sectional areas. Thus, the temperature gradient does not lead to an adverse effect on the beam quality at a high pumping power.

In order to obtain an effective thermal coupling of the solid-state laser crystal to the cooling member, the solid-state laser crystal may be provided with a metal layer, preferably of copper, which is connected via a contact layer made of soft metal, preferably of soft solder or indium, with the cooling surface of the cooling member.

It is an important disadvantage of the known assembly that the solid-state laser crystal has to be secured to the cooling member, e.g. by gluing, soldering, or cold-welding. All of these attachment methods require that surfaces to be securely attached to each other are high quality surfaces, i.e. clean, plane and highly polished surfaces. Further, the attachment methods stress the attached parts mechanically and soldering also stresses soldered parts thermally.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a solid-state laser crystal assembly without the above-mentioned disadvantages.

It is a further object of the present invention to provide a solid-state laser crystal assembly that is easy to disassemble, e.g. for servicing purposes, cheap, and easy to manufacture.

According to a first aspect of the present invention, the above-mentioned objects are fulfilled by a solid-state laser crystal assembly comprising a solid-state laser crystal for emission of a laser beam, a cooling member for dissipation of heat generated by the laser and having a cooling surface, the solid-state laser crystal being positioned adjacent to the cooling surface, and a holder for holding the cooling member and the solid-state laser crystal so that the solid-state laser crystal is in heat dissipating contact with the cooling surface.

According to a second aspect of the present invention, the above-mentioned objects are fulfilled by a method of producing a solid-state laser crystal assembly comprising the steps of positioning a solid-state laser crystal for emission of a laser beam adjacent to a cooling surface of a cooling member for dissipation of heat generated by the laser, and mounting the cooling member and the solid-state laser crystal with a holder so that the solid-state laser crystal is in heat dissipating contact with the cooling surface.

It is an important advantage of the present invention that the solid-state laser crystal is not secured to the cooling member by gluing, soldering, cold-welding, etc. Instead, the solid-state laser crystal is removably positioned at the cooling surface of the cooling member and, during operation of the assembly, is held in this position by the holder. Thus, the requirement of tedious and time consuming working of surfaces of the solid-state laser crystal and the cooling member, respectively, in order to obtain high quality surfaces that may be reliably secured to each other is hereby avoided and thus, manufacture of the solid-state laser crystal assembly is greatly simplified.

Further the assembly may be disassembled, e.g. for exchange of a defect solid-state laser crystal, facilitating service and repair.

The assembly may comprise a thermally conductive compound that is positioned between the solid-state laser crystal and the cooling member for decreasing the thermal resistance between the solid-state laser crystal and the cooling member.

Preferably, the thickness of the layer of thermally conductive compound ranges from 50g to 100 µ.

In a preferred embodiment, the solid-state laser crystal may comprise a reflective coating on the surface facing the cooling member.

The holder may comprise an upper member and a base member, the solid-state laser crystal and the cooling member being held between the upper member and the base member.

In order to reduce the thermal resistance between the solid-state laser crystal and ambient, the base member may contain flow channels for a cooling liquid for absorption and removal of heat conducted through the cooling member to the base member.

The thermal resistance may be further reduced by positioning of a heat pump, such as a thermally conductive element, a peltier element, etc, between the cooling member and the base part for increased transportation of heat from the cooling member to the base part.

Preferably, the cooling member is made of thermally conductive material, such as copper, CVD diamond, etc.

To further increase the dissipation of heat generated in the solid-state laser crystal, the solid-state laser crystal assembly may further comprise a first transparent thermally conductive member being positioned between the cooling surface and the solid-state laser crystal. Preferably, the thermally conductive member is made of a material transparent to the laser beam emitted from the solid-state laser crystal. The thermally conductive member may, for example, be made of sapphire. In a preferred embodiment of the invention the thermally conductive member is bonded to the solid-state laser crystal, for example by anodic bonding of the thermally conductive member to the solid-state laser crystal. The thermally conductive compound then being positioned between the cooling member and the first transparent thermally conductive member.

The cooling member may comprise a transparent opening, the transparent opening being adapted to transmit the laser beam emitted from the solid-state laser crystal. In a preferred embodiment the transparent opening is a boring through the cooling member. Hereby, the heat generated in the solid-state laser crystal may be dissipated through the first transparent thermally conductive member to the cooling surface surrounding the boring through the cooling member.

The solid-state laser crystal may thus be adapted to emit the laser beam through the transparent opening, facilitating mounting of the solid-state laser crystal anywhere in the laser cavity and thus not necessarily as an active end mirror.

To still further increase the dissipation of heat generated in the solid-state laser crystal, the solid-state laser crystal assembly may further comprise a second transparent thermally conductive member being positioned on an opposite site of the laser crystal in relation to the first thermally conductive member. Hereby, the heat generated in the solid-state laser crystal may be transmitted in both directions in relation to the longitudinal direction of the solid-state laser crystal. The first and the second transparent thermally conductive members may by connected or in thermally conductive contact at areas of the members extending beyond the solid-state laser crystal

The second transparent thermally conductive member may be bonded to the opposite site of the solid-state laser crystal in relation to the first thermally conductive member, for example by anodic bonding.

Pumping light may enter the solid-state laser crystal at any angle in relation to its surfaces. In the preferred embodiment, the solid-state laser crystal is a disc laser having the shape of a thin circular plate with an upper surface and a lower surface. When the solid-state laser crystal is positioned in the assembly, the lower surface faces the cooling member and the output laser beam is emitted from the upper surface along a propagation axis that is substantially perpendicular to the upper surface. Preferably, pumping light is emitted towards the upper surface of the solid-state laser crystal at an obtuse angle in relation to the upper surface.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a cut-away cross-sectional view of a solid-state laser crystal assembly according to the present invention,

Fig. 2 shows a solid-state laser crystal assembly according to the present invention, and

Fig. 3 shows a solid-state laser crystal assembly comprising a transparent thermally conductive member.

DESCRIPTION OF A PREFERRED EMBODIMENT

Figs. 1 and 2 show in perspective a solid-state laser crystal assembly 10 according to the present invention. The solid-state laser crystal assembly 10 comprises a solid-state laser crystal 12 for emission of a laser beam 14, and a cooling member 16 for dissipation of heat generated by the solid-state laser crystal12 and having a cooling surface 18. The solid-state laser crystal 12 is positioned adjacent to the cooling surface 18. The assembly 10 also has a holder 20 for holding the cooling member 16 and the solid-state laser crystal 12 so that the solid-state laser crystal 12 is in heat dissipating contact with the cooling surface 18.

A thermally conductive compound 22 is positioned between the solid-state laser crystal 12 and the cooling member 16 for decreasing the thermal resistance between the solid-state laser crystal 12 and the cooling member 16. Preferably, the thickness of the layer of thermally conductive compound ranges from 50 μ to 100 g.

The holder 20 may comprise an upper member 24 and a base member 26, the solid-state laser crystal 12 and the cooling member 16 being held between the upper member 24 and the base member 26 that are kept together by fastening means, such as screws 34.

In order to reduce the thermal resistance between the solid-state laser crystal 12 and ambient, the base member 26 may contain flow channels 28 for a cooling liquid for absorption and removal of heat conducted through the cooling member 16 to the base member 26.

The thermal resistance may be further reduced by positioning of a heat pump 30, such as a thermally conductive element, a peltier element, etc, between the cooling member 16 and the base part 26 for increased transportation of heat from the cooling member 16 to the base part 26.

Pumping light 32 is emitted towards the upper surface of the solid-state laser crystal 12 at an obtuse angle in relation to the upper surface.

Fig. 3 shows a solid-state laser assembly according to an embodiment of the invention. A first transparent thermally conductive member 36 is positioned adjacent the. cooling surface 18 of the cooling member 16, and the solid-state laser crystal is then positioned adjacent to the first transparent thermally conductive member 36, on an opposite side. The first transparent thermally conductive member is made of sapphire, but also any other thermally conductive material transparent for the laser beam emitted by the solid-state laser crystal 12 may be used. The first transparent thermally conductive member 36 is bonded to the solid-state laser crystal 12 by anodic bonding so that an optically clean connection is obtained.

The indentations 40 are adapted to receive at least part of the screws 34 (shown in Fig. 2).

A second transparent thermally conductive member (not shown) may be positioned adjacent to the solid-state laser crystal 12 on the side of the solid-state laser crystal opposite the first transparent thermally conductive member so that heat generated by the solid-state laser crystal may be dissipated in the transparent thermally conductive members and thus conducted away from the solid-state laser crystal in both lengthways directions of the laser rod. The solid-state laser crystal is thus positioned in-between two transparent thermally conductive members in a sandwich-like structure. The. second transparent thermally conductive member may be bonded to the solid-state. laser crystal.

The cooling member 16 has a boring 38, so that a laser beam (not shown) emitted from the solid-state laser 12 may be transmitted through the first transparent thermally conductive member and through the boring 38 of the cooling member 16. Hereby, the laser crystal may be positioned anywhere in a laser cavity (not shown) facilitating emission of light from/incident light at both ends of the laser rod.

When the cooling member has a boring, the effective cooling area of a solid-state laser crystal 12 positioned adjacent the cooling surface 18 is reduced by the sectional area of the boring. To compensate for the reduced cooling area, the transparent thermally conductive member is positioned so that at least a part of the transparent thermally conductive member is positioned adjacent to the cooling surface 18. The heat is thus. dissipated in the transparent thermally conductive member and lead to the cooling member 18. The heat transport in the transparent thermally conductive member is then horizontal but this has only a limited effect on the vertical heat dissipation in the solid-state laser crystal so that no 'thermal lens' effect is seen in the solid-state laser crystal.

The first transparent thermally conductive member 36 is in Fig. 3 shown having a circular disc form, but it is envisaged that the first and second transparent thermally conductive members may obtain any form suitable for being thermally connected to the solid-state laser crystal for cooling the laser crystal.

CLAIMS

1. A solid-state laser crystal assembly comprising

a solid-state laser crystal for emission of a laser beam,

a cooling member for dissipation of heat generated by the laser and having a cooling surface, the solid-state laser crystal being positioned adjacent to the cooling surface, and

a holder for holding the cooling member and the solid-state laser crystal so that the solid-state laser crystal is in heat dissipating contact with the cooling surface.

2. A solid-state laser crystal assembly according to claim 1, wherein the holder further comprises an upper member and a base member, the solid-state laser crystal and the cooling member being held between the upper member and the base member.

3. A solid-state laser crystal assembly according to claim 2, wherein the base member contains flow channels for a cooling liquid.

4. A solid-state laser crystal assembly according to claims 2 or 3, further comprising a heat pump positioned between the cooling member and the base part for increased transportation of heat from the cooling member to the base part.

5. A solid-state laser crystal assembly according to claim 4, wherein the heat pump is a thermally conductive element.

6. A solid-state laser crystal assembly according to claim 5, wherein the heat pump is a peltier element.

7. A solid-state laser crystal assembly according to any of the preceding claims, further comprising a thermally conductive compound positioned between the solid-state laser crystal and the cooling member.

8. A solid-state laser crystal assembly according to any of the preceding claims, wherein the cooling member is made of copper.

9. A solid-state laser crystal assembly according to any of the preceding claims, wherein the solid-state laser crystal assembly further comprises a first transparent thermally conductive member, the first transparent thermally conductive member being positioned between the cooling surface and the solid-state laser crystal.

10.A solid-state laser crystal assembly according to claim 9, wherein the first transparent thermally conductive member is bonded to the solid-state laser crystal.

11.A solid-state laser crystal assembly according to claims 9 or 10, wherein the cooling member comprises a transparent opening, the transparent opening being adapted to transmit the laser beam emitted from the solid-state laser crystal.

12.A solid-state laser crystal assembly according to claim 11, wherein the solid-state laser crystal is adapted to emit the laser beam through the transparent opening.

13.A solid-state laser crystal assembly according to any of claims 9-12, further comprising a second transparent thermally conductive member being positioned on an opposite site of the solid-state laser crystal in relation to the first thermally conductive member.

14.A solid-state laser crystal assembly according to claim 13, wherein the second transparent thermally conductive member is bonded to the solid-state laser crystal.

15.A method of producing a solid-state laser crystal assembly comprising the steps of:

positioning a solid-state laser crystal for emission of a laser beam adjacent to a cooling surface of a cooling member for dissipation of heat generated by the laser, and

holding the cooling member and the solid-state laser crystal with a holder so that the solid-state laser crystal is in heat dissipating contact with the cooling surface.

16. A method according to claim 15, further comprising the steps of

providing a holder with an upper member and a base member, and

positioning the solid-state laser crystal and the cooling member between the upper member and the base member.

17. A method according to claim 16, further comprising the step of providing the base member with flow channels for a cooling liquid.

18. A method according to claims 16 or 17, further comprising the step of positioning a heat pump between the cooling member and the base part for increased transportation of heat from the cooling member to the base part.

19. A method according to claim 18, wherein the heat pump is a thermally conductive element.

20. A method according to claim 19, wherein the heat pump is a peltier element.

21. A method according to any of claims 15-20, further comprising the step of positioning a thermally conductive compound between the solid-state laser crystal and the cooling member.

22. A method according to any of claims 15-21, further comprising the step of providing a cooling member made out of copper.

23. A method according to any of claims 15-22, further comprising the step of positioning a first transparent thermally conductive member between the cooling surface and the solid-state laser crystal.

24. A method according to claim 23, further comprising the step of bonding the first transparent thermally conductive member to the solid-state laser crystal.

25. A method according to claims 23 or 24, further comprising the step of providing a transparent opening in the cooling member, the transparent opening being adapted to transmit the laser beam emitted from the solid-state laser crystal.

26. A method according to claim 25, wherein the solid-state laser crystal is adapted to emit the laser beam through the transparent opening.

27. A method according to any of claims 23-26, further comprising the step of positioning a second transparent thermally conductive member on an opposite site of the solid-state laser crystal in relation to the first thermally conductive member.

28. A method according to claim 27, further comprising the step of bonding the second transparent thermally conductive member to the solid-state laser crystal.

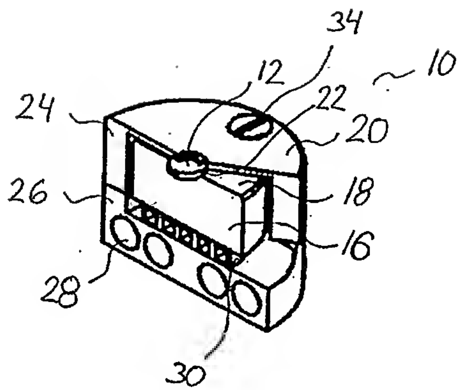

Fig. 1

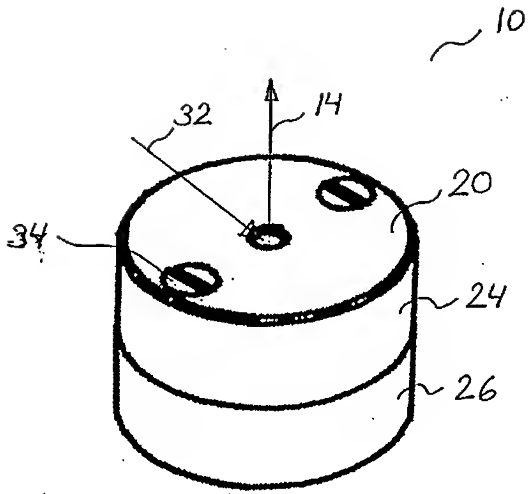

Fig. 2

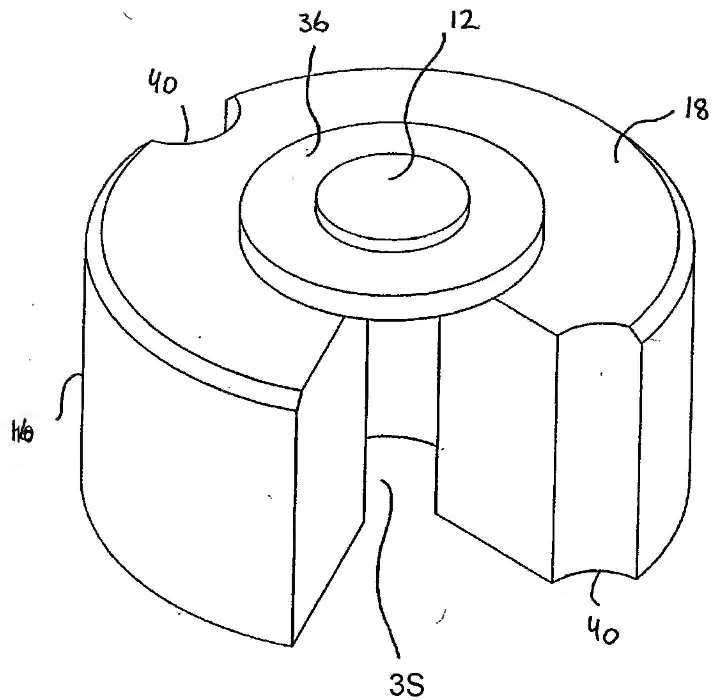

Fig. 3

INTERNATIONAL SEARCH REPORT	Mc Iona! Appftoatbn tto PCT/DK 00/00356

A. CLASSIFICATION OFSu EJECT MATTER
IPC 7 H01S31042

Accordng to International Patent Classification (IPC) or to both national deeeiScetlon and IPC

B. FIELDS SEARCHED

Minimum doc snentatbn searched (clas ifcation system followed by classification symbols)

IPC 7 HO1S

Documentation searched other than minimum documentation to the extent that such documents are Included In the f elcfs searched

Electronic data base consulted during the international search (name of data bane and, where practical. search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category •	Citation of document. with indication, where appropriate, of the relevant passages	Relevant to dain No.
X	WO 98 10494 A (SPIELMANN CHRISTIAN ;KRAUSZ FERENC (AT); STINGL ANDREAS (AT)) 12 March 1998 {1998-03-12) abstract page 10, line 14 -page 11, line 12	1,2,8, 15,16
X	WO 99 27621 A (KRAUSZ FERENC ;STINGL ANDREAS (AT); FEMTOLASERS PRODUKTIONS GMBH 0 3 June 1999 (1999-06-03) the whole document	1-7, 15-20
A	DE 41 32 063 A (DEUTSCHE AEROSPACE) 8 April 1993 {1993-04-08) figure 7	1,9-14

-/—

X Further documents are listed in the continuation of box C.

X Patent family members are listed in annex.

'Special categories of died documents :

•A' document defining the general state of the art which Is not considered to be of particular relevance

earlier document but published on or after the International date

document which may throw doubts on priority claim(*) or which is cited to establish the publication date of another citation or other special reason (as specified)

O' document referring to an oral decloere. use, exhibition or ether means

document published prior to the international toting date but later than the priority date claimed

T later document published after the idematlonal fling date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the Invention

document of particular reievasoe; the claimed invention cannot be considered novel or cannot be considered to involve an Inventive step when the document I. taken alone

document of particular relevance; the claimed invention cannot be considered to Involve an Inventive step when the document Is combined with one or more other suds docrments. such combination being obvious to a person aided in the art

'8' document member of the same patent family

Data of the actual completion of the international search	Date of malting of the international search report
6 October 2000	16/10/2000
Name and mailing address of the ISA European Patent Office, P.R.5818 Pateddfaan 2 NL – 2280 HV Rijswijk Tel. (t31–T0) 340–2040. Tx. 31 851 epo N. Fax: (+31–T0) 34o-3018	Authorized officer Gal anti , M

1

Form PCTASA210 *(second awe') (July 1002)*

C.(CoM4twHon) DOCUMENTS CONSIDERED TO BE RELEVANT

Categcy	CRatlon of document. with on whero appropdete, of the relevant passage.	Relevant to claim No.
A	US 5 553 088 A (BRAUCH UWE ET AL) 3 September 1996 (1996-09-03) cited in the application abstract; figures 2,3	1,3,8,9
A	US 5 581 569 A (TANUMA RYOHEI) 3 December 1996.(1996-12-03) column 4, line 50 - line 55 column 5, line 8 - line 11	1-3
A	US 5 907 570 A (CHENG EMILY ET AL) 25 May 1999 (1999-05-25) figure 3	1,8
A	US 5 331 507 A (KYUNG JOHNNY S ET AL) 19 July 1994 (1994-07-19) column 1, line 21 - line 27; claim 1	

1

INTERNATIONAL SEARCH REPORT

pwomutlon on patent family members

Mt Vend Application No

PCT/DK 00/00356

Patent document cited in aeon* report			Patent family member(s)		
WO 9810494	A	12-03-1998	AT	405992 B	25-01-2000
			AT	158296 A	15-05-1999
			EP	0923797 A	23¯06¯1999
WO 9927621	A	03-06-1999	AT	405776 B	25¯11¯1999
			AT	199297 A	15-03-1999
			AU	9615598 A	15-06-1999
			EP	1034584 A'	13-09-2000
DE 4132063	A	08-04-1993	NONE		
US 5553088	A	03-09-1996	DE	4344227 A	19-01-1995
			DE	59407111 D	26-11°1998
			EP	0632551 A	04¯01-1995
			EP	0869591 A	07¯10-1998
			EP	0869592 A	07-10-1998
US 5581569	A	03-12-1996	JP	7283470 A	- 27-10-1995
US 5907570	A	25-05-1999	EP	1025624 A	09-08-2000
			WO	9921250 A	29-04-1999
US 5331507	A	19-07-1994	NONE		